# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 302



# FULL SCALE TESTS ON A THIN METAL PROPELLER AT VARIOUS TIP SPEEDS

By FRED E. WEICK

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1928

# AERONAUTICAL SYMBOLS

## 1. FUNDAMENTAL AND DERIVED UNITS

| | Symbol | Metric | | English | |
|---|---|---|---|---|---|
| | | Unit | Symbol | Unit | Symbol |
| Length | $l$ | meter | m | foot (or mile) | ft. (or mi.) |
| Time | $t$ | second | sec | second (or hour) | sec. (or hr.) |
| Force | $F$ | weight of one kilogram | kg | weight of one pound | lb. |
| Power | $P$ | kg/m/sec | | horsepower | HP. |
| Speed | | {km/hr | | mi./hr | M. P. H. |
| | | m/sec | | ft./sec | f. p. s. |

## 2. GENERAL SYMBOLS, ETC.

$W$, Weight, $=mg$

$g$, Standard acceleration of gravity $=9.80665$ m/sec.$^2$ $=32.1740$ ft./sec.$^2$

$m$, Mass, $=\frac{W}{g}$

$\rho$, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m$^{-4}$ sec.$^2$) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.$^2$).

Specific weight of "standard" air, 1.2255 kg/m$^3$ $=0.07651$ lb./ft.$^3$

$mk^2$, Moment of inertia (indicate axis of the radius of gyration, $k$, by proper subscript).

$S$, Area.

$S_w$, Wing area, etc.

$G$, Gap.

$b$, Span.

$c$, Chord length.

$b/c$, Aspect ratio.

$f$, Distance from $c.\ g.$ to elevator hinge.

$\mu$, Coefficient of viscosity.

## 3. AERODYNAMICAL SYMBOLS

$V$, True air speed.

$q$, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

$L$, Lift, absolute coefficient $C_L=\frac{L}{qS}$

$D$, Drag, absolute coefficient $C_D=\frac{D}{qS}$

$C$, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

$R$, Resultant force. (Note that these coefficients are twice as large as the old coefficients $L_C$, $D_C$.)

$i_w$ Angle of setting of wings (relative to thrust line).

$i_t$, Angle of stabilizer setting with reference to thrust line.

$\gamma$, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where $l$ is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

$C_p$, Center of pressure coefficient (ratio of distance of $C.\ P.$ from leading edge to chord length).

$\beta$, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

$\alpha$, Angle of attack.

$\epsilon$, Angle of downwash.

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Langley Memorial Aeronautical Laboratory

# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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By Fred E. Weick

### SUMMARY

*This report describes an investigation made in order to determine the effect of tip speed on the characteristics of a thin-bladed metal propeller. The propeller was mounted on a VE–7 airplane with a 180-HP. E–2 engine, and tested in the 20-foot propeller research tunnel of the National Advisory Committee for Aeronautics. It was found that the effect of tip speed on the propulsive efficiency was negligible within the range of the tests, which was from 600 to 1,000 ft. per sec. (about 0.5 to 0.9 the velocity of sound in air).*

### INTRODUCTION

It is known that the nondimensional coefficients of thrust, power, and efficiency, in terms of which propeller characteristics are usually expressed, vary with size and speed; and the size and speed of a propeller are conveniently represented by its tip speed in the plane of rotation.

Tests had been made previously on model propellers at various tip speeds (references 1 to 3) and also on small model airfoils at various air velocities up to and beyond the velocity of sound in air (references 4 and 5). The conditions under which the airfoil tests were made render them purely qualitative in value, but the results of the model propeller tests apparently have some quantitative value. Both sets of tests indicate a serious change in coefficients at the higher speeds, particularly in regard to airfoil drag coefficients (which are higher) and propeller efficiencies (which are very much lower). These tests also indicate that the effect of high speed is less for thin than for thick sections, and, since all of the sections used in these tests were much thicker than the sections of modern metal propellers, it may be inferred that the coefficients for thin metal propellers will be less affected by speed.

The investigation described in this report is the first to obtain the effect of tip speed on the coefficients of a full-scale thin-bladed metal propeller on an actual airplane in a wind tunnel. The tip speeds reached were not quite as high as desirable, but represent the maximum ordinarily found in practice. Even to obtain these tip speeds, it was necessary to set the propeller, which was of the adjustable type, to an unusually low pitch. These tests, therefore, are to be taken as the first step only in a more complete investigation on the effect of tip speeds which is to be made in the near future.

### METHODS AND APPARATUS

The propeller used in this investigation was of the detachable-blade aluminum-alloy type, made in accordance with Navy drawing No. 4413. (Fig. 1.) The thickness ratio of the section nearest the tip was 0.055 and that of the section at 75 per cent of the tip radius was 0.078. The blades were intended for a propeller 9 ft. 6 in. in diameter, but the only hub available was 1 inch short of the standard length (it had been made so to save weight), so that the propeller as tested was actually 9 ft. 5 in. in diameter. In order to obtain the highest practicable tip speed with the power available, the blades were set at the comparatively low blade angle of 7° at the 42 in. radius. This, of course, resulted in a propeller of lower pitch than is found in practice, but had the compensating advantage that any tip speed effect would be exaggerated because of the low pitch.

The tests were made in the propeller research tunnel of the National Advisory Committee for Aeronautics, which has an open jet air stream 20 ft. in diameter capable of velocities up to 110 M. P. H. A complete description of the tunnel, balances, and other measuring apparatus is given in reference 6.

A Vought VE–7 airplane with a Wright E–2, 180 HP. engine, which had been mounted in the tunnel for another investigation (reference 7), was also used for these tests. Since the VE–7 airplane has a span of 34 ft., the wings projected about 7 ft. outside of the air stream. Figure 2 is a photograph of the airplane in the experiment chamber. It is considered that a

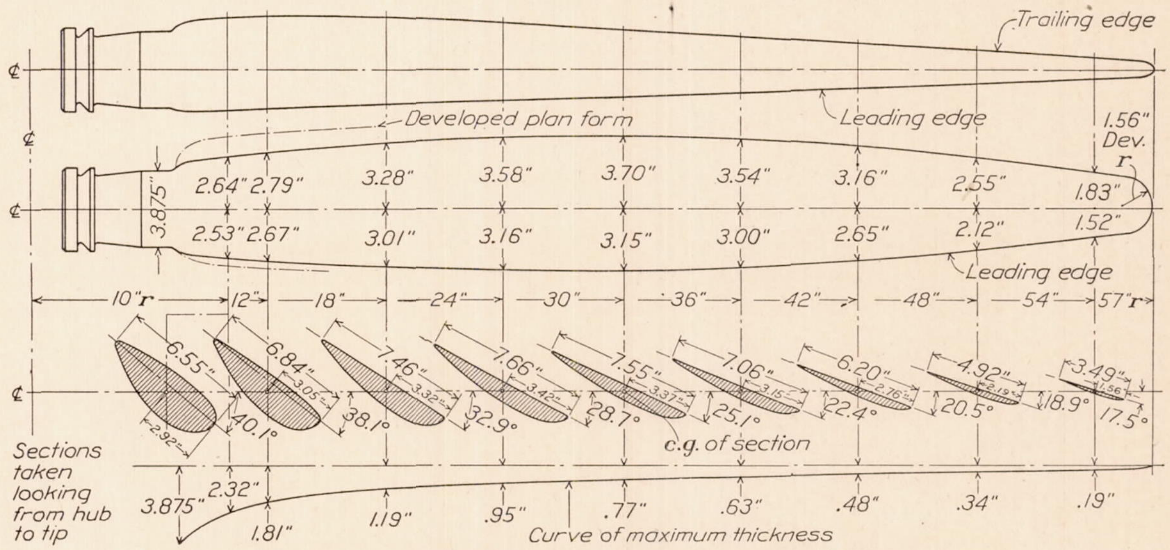


FIG. 1.—Metal propeller blade 9.5 feet in diameter. Right hand. No. 4413

ORDINATES OF SECTIONS AT VARIOUS RADII FOR EXPERIMENTAL METAL PROPELLER BLADE

9.5 ft. diameter, right-hand (fig. 1)

| S | 10″ r | | 12″ r | | 18″ r | 24″ r | 30″ r | 36″ r | 42″ r | 48″ r | 54″ r |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Upper | Lower | Upper | Lower | Upper | Upper | Upper | Upper | Upper | Upper | Upper |
| | ″ | ″ | ″ | ″ | ″ | ″ | ″ | ″ | ″ | ″ | ″ |
| 2.5 | 0.62 | 0.28 | 0.68 | 0.14 | 0.49 | 0.39 | 0.32 | 0.26 | 0.20 | 0.14 | 0.02 |
| 5 | .84 | .44 | .86 | .21 | .70 | .56 | .46 | .37 | .28 | .20 | .08 |
| 10 | 1.13 | .59 | 1.15 | .28 | .94 | .75 | .61 | .50 | .38 | .27 | .11 |
| 20 | 1.45 | .70 | 1.39 | .33 | 1.13 | .90 | .73 | .60 | .46 | .32 | .15 |
| 30 | 1.58 | .74 | 1.46 | .35 | 1.19 | .95 | .77 | .63 | .48 | .34 | .18 |
| 40 | 1.56 | .73 | 1.45 | .35 | 1.18 | .94 | .76 | .62 | .48 | .34 | .19 |
| 50 | 1.50 | .70 | 1.39 | .33 | 1.13 | .90 | .73 | .60 | .46 | .32 | .19 |
| 60 | 1.38 | .64 | 1.27 | .30 | 1.04 | .83 | .67 | .56 | .42 | .30 | .18 |
| 70 | 1.17 | .55 | 1.08 | .26 | .88 | .70 | .57 | .47 | .36 | .23 | .17 |
| 80 | .89 | .42 | .82 | .20 | .67 | .53 | .43 | .35 | .27 | .19 | .14 |
| 90 | .55 | .26 | .51 | .12 | .42 | .33 | .27 | .22 | .17 | .12 | .11 |
| | ″ | | ″ | | | | | | | | |
| Rad. T. E. | 0.21 | | 0.16 | | 0.09 | 0.07 | 0.06 | 0.05 | 0.04 | 0.03 | 0.07 |
| Rad. L. E. | .72 | | .31 | | .12 | .10 | .08 | .06 | .05 | .03 | .01 |
| Chord | 6.55 | | 6.84 | | 7.46 | 7.66 | 7.55 | 7.06 | 6.20 | 4.92 | 3.49 |

The chord is divided into 10 equal parts, or stations, with the one at the leading edge subdivided into halves and quarters. S equals stations in per cent of chord from the leading edge.

sufficient portion of the airplane was in the air stream to include all parts which would react on or be influenced by the propeller.

In order to determine the pitch of the propeller in operation, the deflection of one blade was measured at the 42 in. radius, by means of a telescope mounted on a graduated base and sighted on first the leading and then the trailing edge. This was done while the propeller was standing still and then was repeated for each test point while the propeller was running.

The air velocity was obtained by means of calibrated static plates in the return passages, leading to a manometer in the experiment chamber. The revolution speed of the propeller was read directly from a specially built and calibrated Elgin chronometric tachometer.

The VE-7, as mounted in the tunnel, had completely enclosed within it a special steel skeleton fuselage with a built-in dynamometer to measure the engine and propeller torque directly. (Reference 6.) An observer sat in the rear cockpit of the airplane throughout the tests to operate the engine and read the torque scale and the tachometer.

The resultant horizontal force of the propeller-body combination, which may be either a thrust or a drag, was measured on the regular thrust balance (also described in reference 6).

This resultant horizontal force $R$ may be thought of as composed of three horizontal components, such that

$$R = T - D - \Delta D,$$

where

$T$ = the thrust of the propeller while operating in front of the body (the tension in the crank shaft).

$D$ = the drag of the airplane alone (without propeller) at the same air velocity and density.

$\Delta D$ = the increase in drag of the airplane with propeller, due to the slip stream.

FIG. 2.—VE-7 airplane mounted in propeller research tunnel

In order to obtain the propulsive efficiency, which includes the propeller-body interference, an effective thrust is used which is defined as

$$\text{Effective thrust} = T - \Delta D = R + D.$$

## RESULTS

The results of the tests are given in Figures 3 to 7, inclusive, and in Tables I and II. They are reduced to the usual coefficients of thrust, power, and propulsive efficiency,

$$C_T = \frac{\text{Effective thrust}}{\rho n^2 D^4}$$

$$C_P = \frac{\text{Input power}}{\rho n^3 D^5}$$

$$\eta = \frac{\text{Effective thrust} \times \text{velocity of advance}}{\text{Input power}}$$

where $D$ = propeller diameter and $n$ = revolutions per unit time. Since the coefficients are dimentionless, any homogeneous system of units may be used.

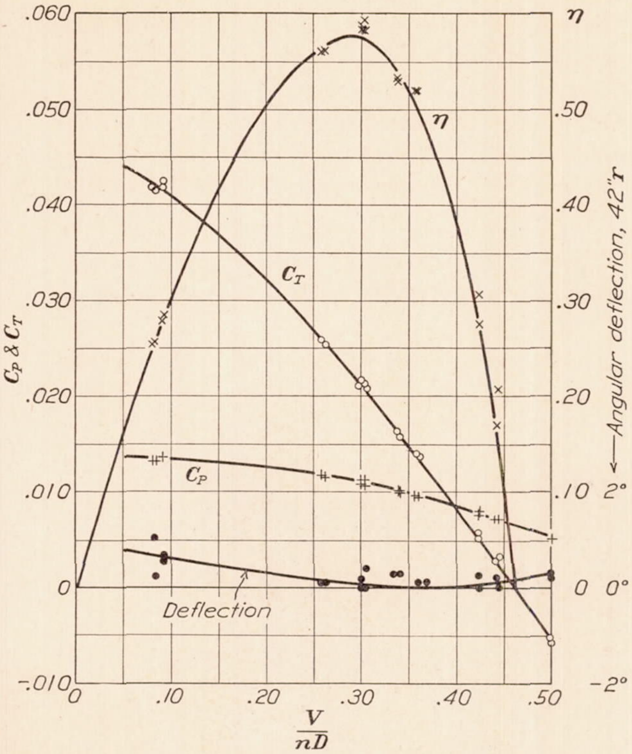


FIG. 3.—Propeller 4413. (7° at 42") on VE-7 airplane. 1,200 R. P. M. Tip speed=591 ft./sec. $V/c$=0.526

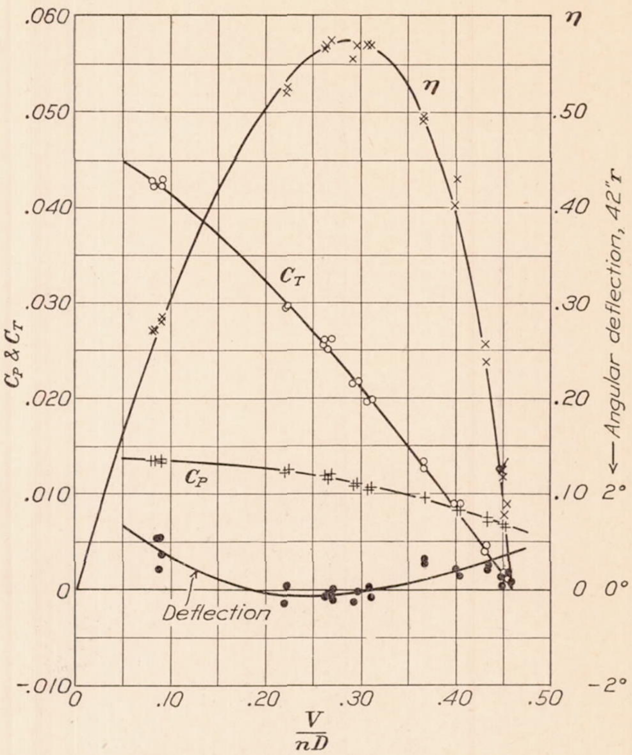


FIG. 4.—Propeller 4413. (7° at 42") on VE-7 airplane. 1,400 R. P. M. Tip speed=690 ft./sec. $V/c$=0.614

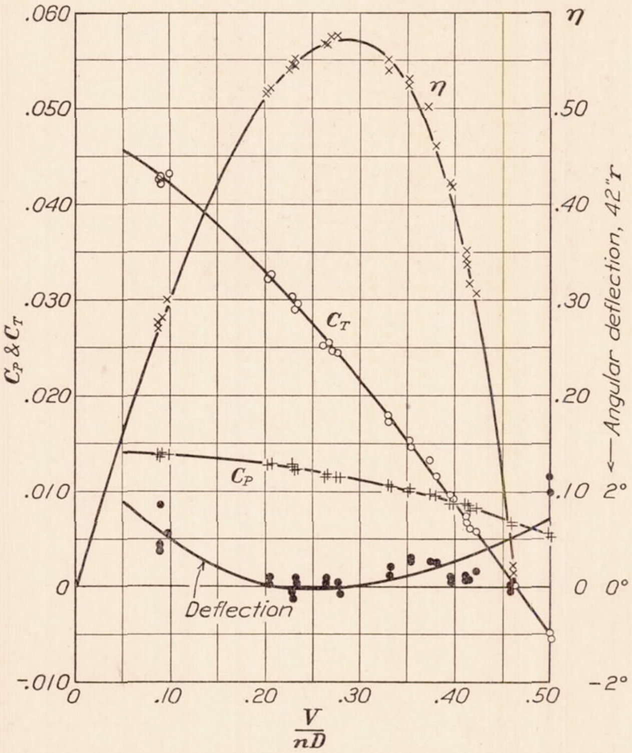


FIG .5.—Propeller 4413. (7° at 42") on VE-7 airplane. 1,600 R. P. M. Tip speed=788 ft./sec. $V/c$=0.702

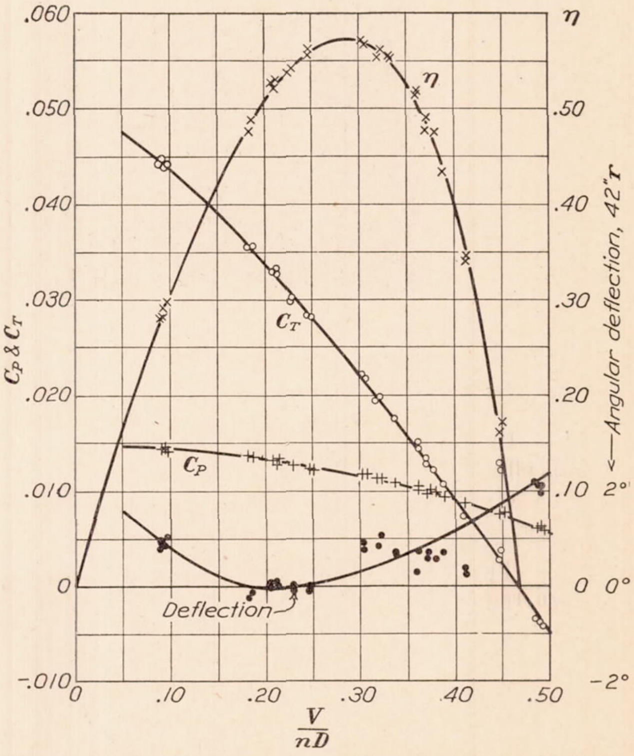


FIG. 6.—Propeller 4413. (7° at 42") on VE-7 airplane. 1,800 R. P. M. Tip speed=887 ft./sec. $V/c$=0.791

The angular deflections at the 42 in. radius, which were measured for each test point, are also plotted in Figures 3 to 7. In general, the deflection was very small at the values of $\frac{V}{nD}$ near maximum efficiency, but at higher and lower values of $\frac{V}{nD}$ there was an increase in the blade angle, which was greater for the higher rotational speeds than for the lower ones.

A comparison of the thrust coefficients obtained at the various rotational speeds (or tip speeds) is given in Figure 8, and a comparison of the power coefficients in Figure 9. It will be noticed that particularly at the low values of $\frac{V}{nD}$, the thrust and power coefficients increase with an increase in tip speed. This can be entirely accounted for by the deflection of the blades in operation, so apparently is not due to scale or compressibility effect to an appreciable extent.

The efficiencies found at the various tip speeds are plotted against $\frac{V}{nD}$ in Figure 10. The curves for all tip speeds are the same within the limits of accuracy of the experiments, indicating

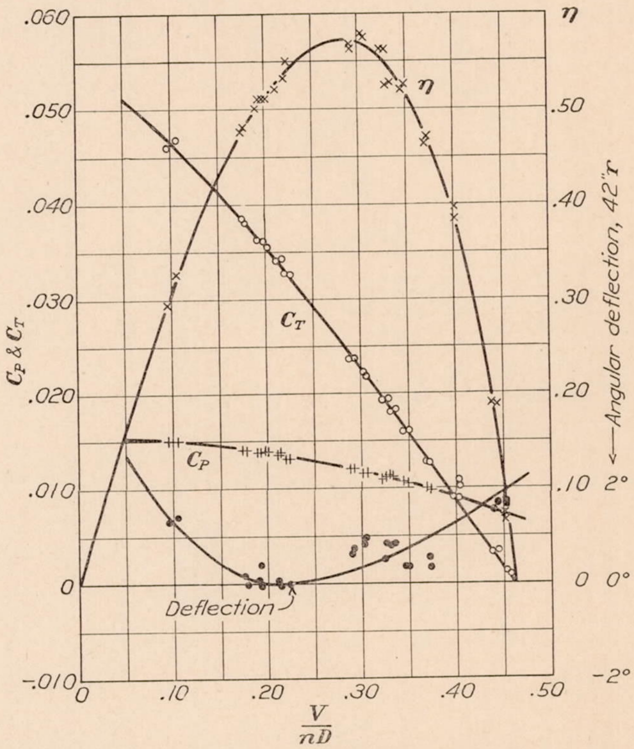


FIG. 7.—Propeller 4413. (7° at 42") on VE-7 airplane. 2,000 R. P. M. Tip speed=986 ft./sec. V/c=0.878

that the effect of tip speed on efficiency is negligible for this particular thin-bladed metal propeller within the range of tip speeds tested (from about 0.5 to 0.9, the velocity of sound in air).

In Figure 11 the efficiencies and values of $\frac{V}{nD}$ are plotted against the factor

$$\sqrt[5]{\frac{\rho V^5}{Pn^2}}$$

This is a form of speed-power coefficient which represents the required performance of a propeller on an airplane, since it includes the power absorbed, the revolutions, and the velocity of advance. Propellers operating at the same value of this coefficient are therefore working under similar requirements, and hence a comparison of efficiencies can be made on a fair basis. Figure 11 shows clearly that from the standpoint of effectiveness of operation on an airplane, the tip speed is of no practical importance within the limits of these experiments.

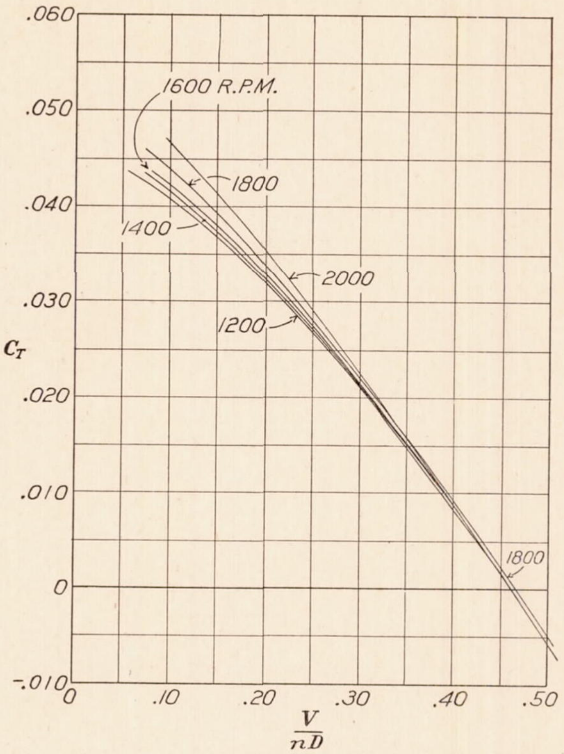


FIG. 8.—Propeller 4413. (7° at 42″) on VE-7 airplane

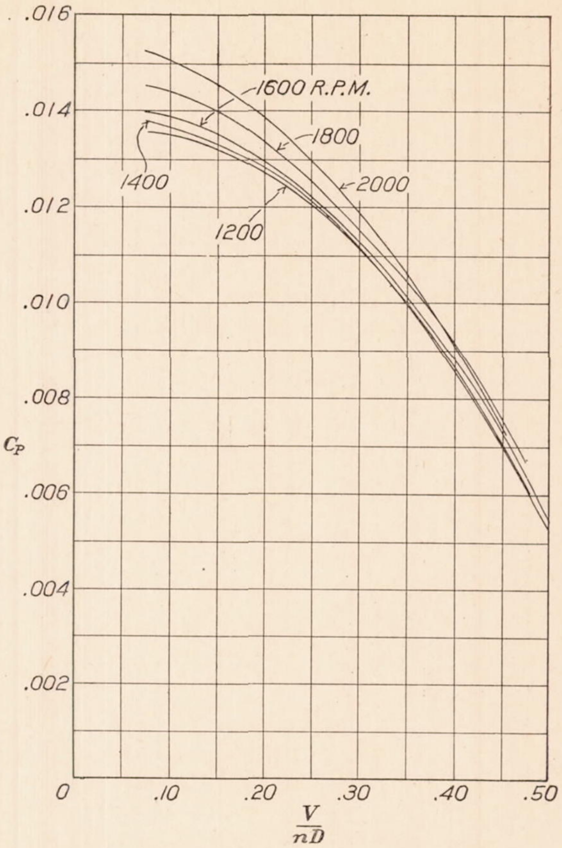


FIG. 9.—Propeller 4413. (7° at 42″) on VE-7 airplane

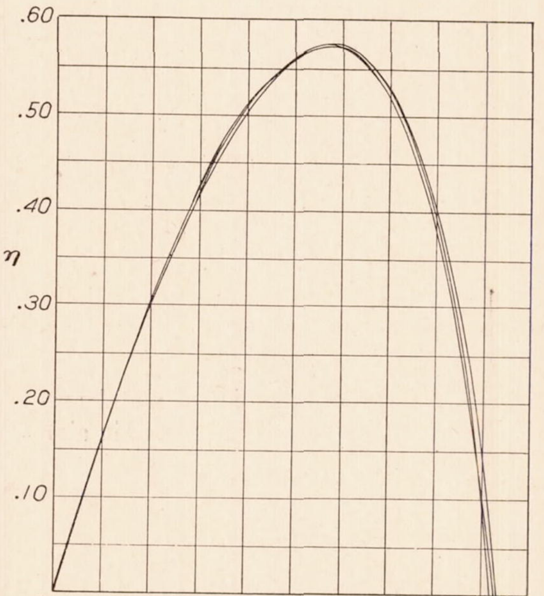


FIG. 10.—Propeller 4413. (7° at 42″) on VE-7 airplane. 1,200, 1,400, 1,600, 1,800, and 2,000 R. P. M. Tip speeds, 591 to 986 ft./sec.

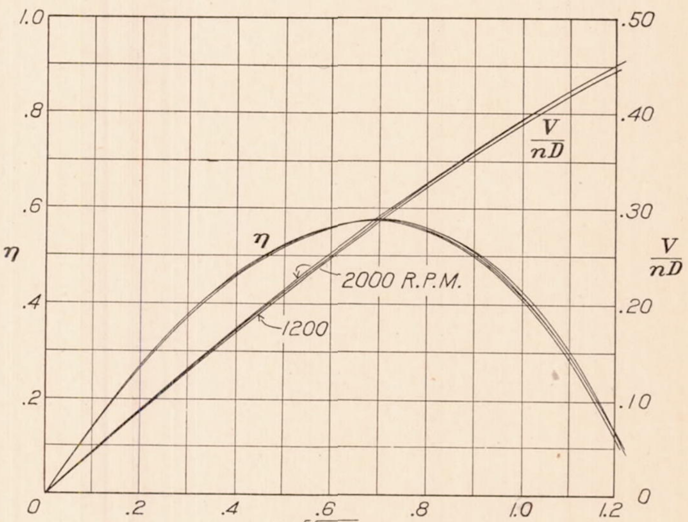


FIG. 11.—Propeller 4413. (7° at 42″) on VE-7 airplane. 1,200, 1,400, 1,600, 1,800, and 2,000 R. P. M. Tip speeds, 591 to 986 ft./sec.

## CONCLUSION

The effect of tip speed on the efficiency and performance coefficients of the propeller tested was negligible throughout the range of the tests, except as the thrust and torque coefficients were affected by the slight change of pitch due to deflection. Apparently the coefficients were not affected by scale or compressibility to an appreciable extent.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *June 20, 1928.*

## REFERENCES


Reference 1. Douglass, G. P., and Wood, R. McKinnon: The Effects of Tip Speed on Airscrew Performance. An Experimental Investigation of the Performance of an Airscrew over a Range of Speeds of Revolution from "Model" Speeds up to Tip Speeds in Excess of the Velocity of Sound in Air. British A. R. C. Reports and Memoranda No. 884, 1923.

Reference 2. Douglass, G. P., and Perring, W. G. A.: Wind Tunnel Tests with High Tip Speed Airscrews. The Characteristics of the Airfoil Section R. A. F. 31a at High Speeds. British A. R. C. Reports and Memoranda No. 1086, 1927.

Reference 3. Douglass, G. P., and Perring, W. G. A.: Wind Tunnel Tests with High Tip Speed Airscrews. The Characteristics of a Bi-convex Airfoil at High Speeds. British A. R. C. Reports and Memoranda No. 1091, 1927.

Reference 4. Briggs, L. J., Hull, G. F., and Dryden, H. L.: The Aerodynamic Characteristics of Airfoils at High Speeds. N. A. C. A. Technical Report No. 207, 1925.

Reference 5. Briggs, L. J., and Dryden, H. L.: Pressure Distribution over Airfoils at High Speeds. N. A. C. A. Technical Report No. 225, 1927.

Reference 6. Weick, Fred E., and Wood, Donald H.: The Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. N. A. C. A. Technical Report No. 300, 1928.

Reference 7. Weick, Fred E.: Full Scale Tests of Wood Propellers on a VE–7 Airplane in the Propeller Research Tunnel. N. A. C. A. Technical Report No. 301, 1928.

TABLE I

TEST DATA

Propeller No. 4413—7° at 42 in.

1,200 R. P. M.

(Tip speed 591.7 ft./sec.)

| $\rho$ | $V$ M. P. H. | $N$ R. P. M. | $Q$ lb. ft. | $T$ lb. | $C_T$ | $C_P$ | $V/nD$ | $\eta$ | Def. at 42 in. Rad., deg. |
|---|---|---|---|---|---|---|---|---|---|
| 0. 002365 | 64. 0 | 1, 205 | 57 | −40 | −0. 00540 | 0. 00515 | 0. 498 | −0. 522 | +0. 2 |
| . 002365 | 63. 8 | 1, 200 | 57 | −41 | −. 00556 | . 00519 | . 499 | −. 535 | . 3 |
| . 002365 | 58. 2 | 1, 230 | 83 | 26 | . 00336 | . 00719 | . 444 | . 208 | . 0 |
| . 002365 | 58. 2 | 1, 235 | 85 | 22 | . 00281 | . 00730 | . 442 | . 170 | . 2 |
| . 002364 | 54. 3 | 1, 205 | 88 | 43 | . 00577 | . 00794 | . 423 | . 307 | . 2 |
| . 002364 | 54. 1 | 1, 195 | 87 | 38 | . 00520 | . 00800 | . 424 | . 276 | . 0 |
| . 002378 | 10. 7 | 1, 220 | 152 | 317 | . 0414 | . 0133 | . 0825 | . 257 | . 3 |
| . 002378 | 10. 7 | 1, 220 | 152 | 317 | . 0414 | . 0133 | . 0825 | . 257 | 1. 0 |
| . 00234 | 11. 65 | 1, 205 | 149 | 311 | . 0424 | . 01356 | . 0905 | . 284 | . 7 |
| . 00234 | 11. 65 | 1, 205 | 149 | 307 | . 0418 | . 01350 | . 0905 | . 281 | . 6 |
| . 002378 | 39. 2 | 1, 210 | 121 | 158 | . 0210 | . 01078 | . 304 | . 591 | . 4 |
| . 002378 | 39. 2 | 1, 210 | 124 | 159 | . 0211 | . 01104 | . 304 | . 581 | . 0 |
| . 002375 | 43. 8 | 1, 215 | 115 | 122 | . 01605 | . 0101 | . 338 | . 535 | . 3 |
| . 002375 | 43. 8 | 1, 215 | 115 | 122 | . 01605 | . 0101 | . 338 | . 535 | . 3 |
| . 002369 | 45. 6 | 1, 195 | 104 | 101 | . 0138 | . 00954 | . 358 | . 519 | . 1 |
| . 002369 | 45. 6 | 1, 195 | 105 | 101 | . 0138 | . 00961 | . 358 | . 514 | . 1 |
| . 002369 | 38. 4 | 1, 200 | 123 | 160 | . 0217 | . 01118 | . 300 | . 582 | . 0 |
| . 002369 | 38. 2 | 1, 195 | 120 | 157 | . 0214 | . 01096 | . 300 | . 586 | . 2 |
| . 002367 | 32. 0 | 1, 165 | 123 | 180 | . 0258 | . 0118 | . 258 | . 563 | . 1 |
| . 002367 | 32. 0 | 1, 155 | 120 | 174 | . 0254 | . 01174 | . 2605 | . 563 | . 1 |

1,400 R. P. M.

(Tip speed 690.3 ft./sec.)

| $\rho$ | $V$ M. P. H. | $N$ R. P. M. | $Q$ lb. ft. | $T$ lb. | $C_T$ | $C_P$ | $V/nD$ | $\eta$ | Def. at 42 in. Rad., deg. |
|---|---|---|---|---|---|---|---|---|---|
| 0. 002365 | 68. 4 | 1, 410 | 104 | 14 | 0. 00138 | 0. 00687 | 0. 453 | 0. 0912 | +0. 4 |
| . 002365 | 68. 2 | 1, 415 | 106 | 13 | . 00127 | . 00695 | . 451 | . 0825 | . 3 |
| . 00237 | 67. 1 | 1, 400 | 106 | 20 | . 00199 | . 00707 | . 449 | . 1265 | . 5 |
| . 00237 | 66. 8 | 1, 395 | 105 | 19 | . 0019 | . 00705 | . 449 | . 121 | . 1 |
| . 002365 | 64. 9 | 1, 410 | 116 | 47 | . 00461 | . 00765 | . 432 | . 260 | . 5 |
| . 002365 | 64. 9 | 1, 405 | 113 | 42 | . 00415 | . 00747 | . 433 | . 241 | . 4 |
| . 002365 | 59. 3 | 1, 395 | 131 | 90 | . 00900 | . 00883 | . 399 | . 406 | . 4 |
| . 002365 | 59. 3 | 1, 385 | 127 | 90 | . 00915 | . 00852 | . 402 | . 432 | . 3 |
| . 002362 | 55. 4 | 1, 425 | 152 | 139 | . 0134 | . 00983 | . 365 | . 496 | . 7 |
| . 002362 | 55. 4 | 1, 425 | 151 | 137 | . 0132 | . 00973 | . 365 | . 494 | . 6 |
| . 002378 | 13. 6 | 1, 405 | 207 | 430. 5 | . 0424 | . 01364 | . 0909 | . 283 | . 8 |
| . 002378 | 13. 6 | 1, 405 | 206 | 434. 5 | . 0429 | . 01360 | . 0909 | . 287 | 1. 1 |
| . 00234 | 13. 25 | 1, 405 | 204 | 427 | . 0428 | . 0137 | . 0882 | . 274 | . 5 |
| . 00234 | 13. 25 | 1, 405 | 205 | 422 | . 0424 | . 01374 | . 0882 | . 272 | 1. 1 |
| . 002380 | 38. 3 | 1, 375 | 175 | 255 | . 0262 | . 01203 | . 2615 | . 569 | −. 1 |
| . 002380 | 38. 3 | 1, 375 | 173 | 252 | . 0259 | . 01190 | . 2615 | . 569 | −. 1 |
| . 002375 | 40. 9 | 1, 425 | 175 | 229 | . 0219 | . 01127 | . 2955 | . 573 | . 0 |
| . 002375 | 44. 2 | 1, 420 | 175 | 224 | . 02160 | . 0113 | . 292 | . 557 | −. 2 |
| . 002369 | 45. 8 | 1, 400 | 160 | 200 | . 0199 | . 01066 | . 307 | . 573 | +. 1 |
| . 002369 | 45. 8 | 1, 385 | 160 | 197 | . 0200 | . 01085 | . 310 | . 572 | −. 1 |
| . 002369 | 39. 1 | 1, 365 | 175 | 253 | . 0264 | . 01229 | . 269 | . 578 | . 0 |
| . 002369 | 38. 7 | 1, 375 | 170 | 246 | . 0254 | . 01172 | . 264 | . 572 | −. 2 |
| . 002367 | 32. 9 | 1, 400 | 187 | 297 | . 0296 | . 01250 | . 2205 | . 522 | +. 1 |
| . 002367 | 32. 9 | 1, 390 | 185 | 295 | . 0298 | . 01252 | . 222 | . 528 | −. 2 |

TABLE I—Continued

TEST DATA—Continued

1,600 R. P. M.

(Tip speed 788.9 ft./sec.)

| $\rho$ | $V$ M. P. H. | $N$ R. P. M. | $Q$ lb. ft. | $T$ lb. | $C_T$ | $C_P$ | $V/nD$ | $\eta$ | Def. at 42 in. Rad., deg. |
|---|---|---|---|---|---|---|---|---|---|
| 0. 00238 | 83. 8 | 1, 575 | 106 | −62 | −0. 00485 | 0. 0056 | 0. 498 | −0. 432 | +2. 4 |
| . 00238 | 83. 8 | 1, 565 | 102 | −69 | −. 00546 | . 0054 | . 500 | −. 506 | 2. 0 |
| . 002365 | 78. 3 | 1, 600 | 133 | 3 | . 000229 | . 00678 | . 458 | . 0155 | −. 1 |
| . 002365 | 78. 4 | 1, 605 | 133 | 4 | . 000330 | . 00675 | . 458 | . 0224 | +. 1 |
| . 002365 | 71. 9 | 1, 595 | 158 | 77 | . 00593 | . 00812 | . 422 | . 308 | . 4 |
| . 002365 | 70. 7 | 1, 595 | 158 | 81 | . 00622 | . 00812 | . 415 | . 318 | . 2 |
| . 002365 | 69. 6 | 1, 585 | 167 | 96 | . 00745 | . 00867 | . 411 | . 353 | . 2 |
| . 002365 | 69. 2 | 1, 575 | 164 | 91 | . 00715 | . 00861 | . 412 | . 342 | . 3 |
| . 00237 | 67. 2 | 1, 605 | 177 | 127 | . 00959 | . 00895 | . 395 | . 423 | . 1 |
| . 00237 | 67. 7 | 1, 605 | 177 | 127 | . 00959 | . 00895 | . 395 | . 423 | . 2 |
| . 002365 | 63. 7 | 1, 600 | 192 | 174 | . 0133 | . 00985 | . 373 | . 504 | . 5 |
| . 002365 | 65. 0 | 1, 605 | 188 | 153 | . 0116 | . 00955 | . 380 | . 462 | . 5 |
| . 002365 | 60. 1 | 1, 600 | 199 | 199 | . 0152 | . 01018 | . 352 | . 526 | . 5 |
| . 002365 | 60. 1 | 1, 600 | 197 | 199 | . 0152 | . 01008 | . 352 | . 530 | . 6 |
| . 002362 | 56. 1 | 1, 595 | 208 | 233 | . 0179 | . 01068 | . 330 | . 552 | . 3 |
| . 002362 | 56. 1 | 1, 590 | 207 | 226 | . 0175 | . 0107 | . 331 | . 540 | . 5 |
| . 022378 | 14. 9 | 1, 600 | 267 | 561 | . 0426 | . 01356 | . 0873 | . 275 | . 9 |
| . 002378 | 14. 9 | 1, 595 | 269 | 560 | . 0428 | . 0138 | . 0877 | . 273 | . 8 |
| . 002342 | 15. 25 | 1, 585 | 264 | 551 | . 0432 | . 01386 | . 0900 | . 281 | 1. 7 |
| . 00234 | 16. 20 | 1, 560 | 257 | 533 | . 0431 | . 01395 | . 0971 | . 300 | 1. 1 |
| . 00238 | 40. 3 | 1, 650 | 267 | 427 | . 0304 | . 01275 | . 229 | . 546 | −. 2 |
| . 00238 | 40. 2 | 1, 655 | 269 | 427 | . 0303 | . 01278 | . 228 | . 541 | −. 1 |
| . 002375 | 45. 3 | 1, 615 | 235 | 340 | . 0253 | . 01168 | . 263 | . 568 | +. 1 |
| . 002375 | 45. 3 | 1, 600 | 234 | 334 | . 0254 | . 01185 | . 265 | . 567 | . 2 |
| . 002369 | 46. 4 | 1, 575 | 223 | 312 | . 0245 | . 01172 | . 276 | . 576 | . 1 |
| . 002369 | 46. 3 | 1, 575 | 222 | 312 | . 0245 | . 0117 | . 276 | . 578 | −. 1 |
| . 002369 | 39. 2 | 1, 585 | 240 | 377 | . 0292 | . 01239 | . 232 | . 547 | +. 2 |
| . 002369 | 39. 2 | 1, 585 | 238 | 379 | . 0294 | . 01239 | . 232 | . 552 | . 1 |
| . 002367 | 34. 3 | 1, 580 | 248 | 417 | . 0326 | . 01296 | . 2035 | . 520 | . 2 |
| . 002367 | 33. 9 | 1, 565 | 243 | 406 | . 0323 | . 01296 | . 203 | . 516 | . 1 |

1,800 R. P. M.

(Tip speed 887.5 ft./sec.)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0. 00238 | 85. 0 | 1, 780 | 187 | 45. 5 | 0. 00278 | 0. 0076 | 0. 446 | 0. 163 | +2. 6 |
| . 00238 | 85. 0 | 1, 775 | 185 | 47 | . 002895 | . 0076 | . 449 | . 171 | 2. 5 |
| . 002365 | 93. 3 | 1, 800 | 152 | −58 | −. 00350 | . 0061 | . 485 | −. 278 | 2. 2 |
| . 002365 | 93. 2 | 1, 790 | 149 | −61 | −. 00372 | . 0061 | . 488 | −. 298 | 2. 1 |
| . 00236 | 95. 6 | 1, 820 | 152 | −71 | −. 00420 | . 0060 | . 491 | −. 343 | 2. 0 |
| . 00236 | 95. 6 | 1, 825 | 153 | −71 | −. 00417 | . 0060 | . 491 | −. 341 | 2. 1 |
| . 002365 | 79. 3 | 1, 810 | 218 | 123 | . 00733 | . 00870 | . 411 | . 346 | . 3 |
| . 00236 | 78. 9 | 1, 805 | 217 | 120 | . 00727 | . 00870 | . 410 | . 342 | . 4 |
| . 002365 | 72. 9 | 1, 765 | 223 | 168 | . 01053 | . 00936 | . 387 | . 435 | . 7 |
| . 002365 | 70. 9 | 1, 750 | 228 | 191 | . 01220 | . 00975 | . 379 | . 475 | . 6 |
| . 002365 | 71. 2 | 1, 795 | 246 | 217 | . 01320 | . 0100 | . 371 | . 490 | . 7 |
| . 002365 | 70. 9 | 1, 795 | 244 | 211 | . 01280 | . 00991 | . 370 | . 477 | . 6 |
| . 00237 | 68. 9 | 1, 795 | 249 | 240 | . 01455 | . 0101 | . 360 | . 519 | . 3 |
| . 00237 | 68. 5 | 1, 785 | 251 | 240 | . 0147 | . 0103 | . 360 | . 514 | . 8 |
| . 002365 | 64. 8 | 1, 800 | 266 | 293 | . 01768 | . 01075 | . 337 | . 554 | . 6 |
| . 002365 | 64. 3 | 1, 795 | 263 | 289 | . 0175 | . 0107 | . 336 | . 550 | . 6 |
| . 002365 | 61. 4 | 1, 805 | 278 | 324 | . 0194 | . 01115 | . 318 | . 554 | . 9 |
| . 002365 | 61. 4 | 1, 785 | 275 | 321 | . 01965 | . 01128 | . 322 | . 562 | 1. 1 |
| . 002362 | 57. 2 | 1, 780 | 281 | 356 | . 02195 | . 0116 | . 302 | . 570 | . 9 |
| . 002362 | 57. 0 | 1, 770 | 277 | 351 | . 0219 | . 0116 | . 302 | . 570 | . 8 |
| . 002378 | 18. 0 | 1, 835 | 376 | 769 | . 0444 | . 0145 | . 0919 | . 282 | . 9 |
| . 002378 | 18. 0 | 1, 835 | 377 | 779 | . 0448 | . 01455 | . 0919 | . 284 | . 9 |
| . 002342 | 18. 45 | 1, 820 | 360 | 741 | . 0441 | . 0144 | . 0947 | . 291 | . 8 |
| . 002342 | 18. 85 | 1, 820 | 359 | 742 | . 0442 | . 01432 | . 0967 | . 299 | 1. 0 |
| . 002380 | 40. 9 | 1, 800 | 333 | 557 | . 0333 | . 01335 | . 213 | . 529 | . 0 |
| . 002378 | 40. 8 | 1, 805 | 331 | 554 | . 0330 | . 01320 | . 212 | . 530 | . 1 |
| . 002375 | 43. 5 | 1, 780 | 308 | 488 | . 0299 | . 01270 | . 229 | . 538 | −. 1 |
| . 002375 | 43. 3 | 1, 770 | 305 | 486 | . 0301 | . 01268 | . 229 | . 542 | . 0 |
| . 002365 | 46. 8 | 1, 775 | 300 | 457 | . 0283 | . 01245 | . 247 | . 561 | −. 1 |
| . 002365 | 46. 8 | 1, 775 | 300 | 453 | . 0282 | . 01245 | . 247 | . 558 | . 0 |
| . 002371 | 39. 5 | 1, 765 | 316 | 528 | . 0330 | . 01325 | . 210 | . 523 | . 0 |
| . 002371 | 39. 5 | 1, 775 | 315 | 534 | . 0330 | . 01308 | . 2085 | . 527 | +. 1 |
| . 002367 | 35. 9 | 1, 810 | 341 | 598 | . 0356 | . 01356 | . 186 | . 488 | −. 1 |
| . 002367 | 35. 3 | 1, 805 | 342 | 597 | . 0357 | . 0137 | . 1836 | . 478 | −. 2 |

TABLE I—Continued

TEST DATA—Continued

2,000 R. P. M.

(Tip speed 986.1 ft./sec.)

| $\rho$ | $V$ M. P. H. | $N$ R. P. M. | $Q$ lb. ft. | $T$ lb. | $C_T$ | $C_P$ | $V/nD$ | $\eta$ | Def. at 42 in. Rad., deg. |
|---|---|---|---|---|---|---|---|---|---|
| 0. 00238 | 85. 8 | 2, 000 | 285 | 190 | 0. 00922 | 0. 0093 | 0. 401 | 0. 398 | +2. 2 |
| . 00238 | 85. 8 | 1, 995 | 282 | 181 | . 00881 | . 0092 | . 402 | . 385 | 2. 1 |
| . 002365 | 94. 1 | 2, 005 | 240 | 69 | . 00336 | . 0078 | . 444 | . 190 | 1. 7 |
| . 002365 | 94. 1 | 2, 010 | 238 | 69 | . 00334 | . 0078 | . 440 | . 190 | 1. 6 |
| . 00236 | 96. 1 | 1, 985 | 217 | 24 | . 001194 | . 0072 | . 454 | . 0754 | 1. 7 |
| . 00236 | 96. 0 | 1, 980 | 215 | 22 | . 001102 | . 0072 | . 454 | . 0695 | 1. 7 |
| . 002365 | 80. 1 | 2, 020 | 312 | 264 | . 01263 | . 01002 | . 371 | . 468 | . 6 |
| . 002365 | 80. 1 | 2, 020 | 314 | 266 | . 01272 | . 01009 | . 371 | . 470 | . 4 |
| . 002365 | 73. 2 | 1, 985 | 323 | 328 | . 01625 | . 01072 | . 345 | . 523 | . 4 |
| . 002365 | 74. 3 | 1, 995 | 321 | 327 | . 01605 | . 01058 | . 348 | . 528 | . 4 |
| . 002365 | 72. 1 | 2, 010 | 351 | 376 | . 0182 | . 01139 | . 334 | . 535 | . 8 |
| . 002365 | 72. 1 | 2, 035 | 360 | 382 | . 01805 | . 01138 | . 331 | . 526 | . 8 |
| . 00237 | 69. 5 | 1, 995 | 339 | 397 | . 0194 | . 01113 | . 324 | . 564 | . 5 |
| . 00237 | 70. 0 | 2, 000 | 345 | 398 | . 0194 | . 01126 | . 327 | . 564 | . 9 |
| . 002365 | 65. 7 | 2, 015 | 361 | 457 | . 0220 | . 0116 | . 305 | . 578 | 1. 0 |
| . 002365 | 65. 5 | 2, 015 | 361 | 458 | . 0221 | . 01160 | . 304 | . 580 | . 9 |
| . 002365 | 62. 2 | 1, 995 | 371 | 480 | . 02355 | . 01218 | . 292 | . 565 | . 8 |
| . 002365 | 62. 2 | 2, 005 | 373 | 490 | . 00238 | . 01215 | . 290 | . 569 | . 6 |
| . 002342 | 20. 2 | 1, 960 | 440 | 898 | . 0462 | . 01512 | . 0962 | . 294 | 1. 3 |
| . 002342 | 22. 4 | 1, 990 | 451 | 941 | . 0468 | . 01502 | . 1052 | . 327 | 1. 4 |
| . 00238 | 43. 0 | 2, 000 | 431 | 735 | . 0357 | . 0140 | . 2015 | . 513 | -------- |
| . 00238 | 42. 5 | 2, 005 | 433 | 748 | . 0361 | . 01403 | . 1985 | . 511 | . 4 |
| . 002376 | 45. 6 | 2, 010 | 422 | 711 | . 0342 | . 01363 | . 212 | . 532 | . 1 |
| . 002376 | 45. 7 | 2, 010 | 424 | 711 | . 0342 | . 01373 | . 214 | . 531 | . 0 |
| . 00237 | 47. 7 | 2, 000 | 405 | 671 | . 0326 | . 0132 | . 223 | . 551 | . 0 |
| . 00237 | 47. 7 | 2, 010 | 417 | 679 | . 0327 | . 0135 | . 221 | . 535 | . 0 |
| . 002369 | 41. 1 | 1, 985 | 415 | 735 | . 0363 | . 0138 | . 1941 | . 512 | . 0 |
| . 002369 | 40. 3 | 1, 985 | 416 | 735 | . 0363 | . 01382 | . 191 | . 502 | . 1 |
| . 002367 | 37. 1 | 1, 960 | 415 | 750 | . 0381 | . 01410 | . 1777 | . 480 | . 0 |
| . 002367 | 36. 7 | 1, 960 | 415 | 755 | . 0384 | . 01410 | . 1758 | . 478 | . 2 |

TABLE II

FINAL ADJUSTED COEFFICIENTS

Propeller No. 4413—7° at 42 in. Rad.

1,200 R. P. M.

(Tip speed 591.7 ft./sec.)

| $\frac{V}{nD}$ | $C_T$ | $C_P$ | $\eta$ | $\sqrt{\frac{\rho V^5}{Pn^2}}$ | $\sqrt[5]{\frac{\rho V^5}{Pn^2}}$ |
|---|---|---|---|---|---|
| 0. 10 | 0. 0409 | 0. 0135 | 0. 302 | 0. 0272 | 0. 234 |
| . 15 | . 0369 | . 0132 | . 419 | . 0760 | . 356 |
| . 20 | . 0321 | . 0127 | . 504 | . 158 | . 479 |
| . 25 | . 0269 | . 0120 | . 560 | . 286 | . 607 |
| . 30 | . 0211 | . 0110 | . 575 | . 470 | . 740 |
| . 35 | . 0142 | . 0100 | . 519 | . 725 | . 879 |
| . 40 | . 00815 | . 0086 | . 379 | 1. 09 | 1. 035 |
| . 45 | . 0016 | . 0070 | . 103 | 1. 622 | 1. 214 |

1,400 R. P. M.

(Tip speed 690.3 ft./sec.)

| | | | | | |
|---|---|---|---|---|---|
| 0. 10 | 0. 0415 | 0. 0136 | 0. 305 | 0. 0271 | 0. 234 |
| . 15 | . 03725 | . 0133 | . 420 | . 0758 | . 356 |
| . 20 | . 0325 | . 0129 | . 503 | . 1576 | . 476 |
| . 25 | . 0271 | . 0121 | . 560 | . 284 | . 604 |
| . 30 | . 0211 | . 0110 | . 575 | . 470 | . 739 |
| . 35 | . 0150 | . 0100 | . 525 | . 725 | . 880 |
| . 40 | . 0086 | . 0087 | . 396 | 1. 086 | 1. 035 |
| . 45 | . 0015 | . 0070 | . 0965 | 1. 622 | 1. 213 |

TABLE II—Continued

FINAL ADJUSTED COEFFICIENTS—Continued

1,600 R. P. M.

(Tip speed 788.9 ft./sec.)

| $\frac{V}{nD}$ | $C_T$ | $C_P$ | $\eta$ | $\sqrt{\frac{\rho V^5}{Pn^2}}$ | $\sqrt[5]{\frac{\rho V^5}{Pn^2}}$ |
|---|---|---|---|---|---|
| 0.10 | 0.0421 | 0.0138 | 0.305 | 0.02696 | 0.234 |
| .15 | .0380 | .0135 | .422 | .0751 | .356 |
| .20 | .0330 | .0129 | .511 | .1575 | .479 |
| .25 | .0274 | .0122 | .560 | .285 | .605 |
| .30 | .0215 | .0113 | .571 | .464 | .735 |
| .35 | .0153 | .0101 | .530 | .721 | .8775 |
| .40 | .0088 | .0089 | .396 | 1.071 | 1.0278 |
| .45 | .0018 | .0072 | .1125 | 1.601 | 1.207 |

1,800 R. P. M.

(Tip speed 887.5 ft./sec.)

| | | | | | |
|---|---|---|---|---|---|
| 0.10 | 0.0438 | 0.01445 | 0.303 | 0.02635 | 0.234 |
| .15 | .0392 | .0140 | .420 | .0737 | .351 |
| .20 | .0339 | .0133 | .509 | .1550 | .475 |
| .25 | .0281 | .01255 | .560 | .2785 | .600 |
| .30 | .0220 | .01155 | .570 | .459 | .733 |
| .35 | .0158 | .01050 | .526 | .709 | .8715 |
| .40 | .0093 | .0092 | .405 | 1.052 | 1.0205 |
| .45 | .00245 | .0075 | .147 | 1.570 | 1.196 |

2,000 R. P. M.

(Tip speed 986.1 ft./sec.)

| | | | | | |
|---|---|---|---|---|---|
| 0.10 | 0.0467 | 0.0151 | 0.309 | 0.0276 | 0.234 |
| .15 | .0415 | .0146 | .426 | .0721 | .349 |
| .20 | .0356 | .0139 | .511 | .1520 | .471 |
| .25 | .0292 | .0130 | .561 | .274 | .595 |
| .30 | .0226 | .0119 | .570 | .452 | .729 |
| .35 | .0157 | .0106 | .518 | .705 | .8795 |
| .40 | .0089 | .0092 | .388 | 1.052 | 1.0205 |
| .45 | .0019 | .0074 | .1154 | 1.58 | 1.200 |

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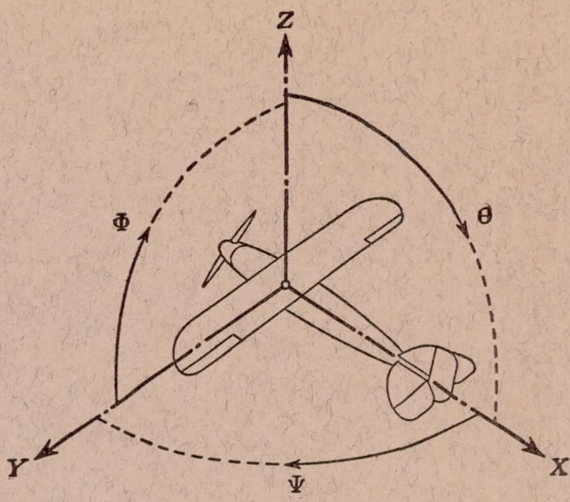


Positive directions of axes and angles (forces and moments) are shown by arrows

| Axis | | Force (parallel to axis) symbol | Moment about axis | | | Angle | | Velocities | |
|---|---|---|---|---|---|---|---|---|---|
| Designation | Symbol | | Designation | Symbol | Positive direction | Designation | Symbol | Linear (component along axis) | Angular |
| Longitudinal | $X$ | $X$ | rolling | $L$ | $Y \longrightarrow Z$ | roll | $\Phi$ | $u$ | $p$ |
| Lateral | $Y$ | $Y$ | pitching | $M$ | $Z \longrightarrow X$ | pitch | $\Theta$ | $v$ | $q$ |
| Normal | $Z$ | $Z$ | yawing | $N$ | $X \longrightarrow Y$ | yaw | $\Psi$ | $w$ | $r$ |

Absolute coefficients of moment

$$C_L = \frac{L}{qbS} \quad C_M = \frac{M}{qcS} \quad C_N = \frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), $\delta$. (Indicate surface by proper subscript.)

## 4. PROPELLER SYMBOLS

$D$, Diameter.
$p_e$, Effective pitch
$p_g$, Mean geometric pitch.
$p_s$, Standard pitch.
$p_v$, Zero thrust.
$p_a$, Zero torque.
$p/D$, Pitch ratio.
$V'$, Inflow velocity.
$V_s$, Slip stream velocity.

$T$, Thrust.
$Q$, Torque.
$P$, Power.
(If "coefficients" are introduced all units used must be consistent.)
$\eta$, Efficiency $= T\,V/P$.
$n$, Revolutions per sec., r. p. s.
$N$, Revolutions per minute., R. P. M.
$\Phi$, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi rn}\right)$

## 5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.